Renewable and Sustainable Energy Reviews 38 (2014) 651–655

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Biodiesel produced from crambe oil in Brazil—A study of performance and emissions in a diesel cycle engine generator

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ARTICLE INFO

Article history:
Received 5 July 2013
Accepted 6 July 2014
Available online 23 July 2014

Keywords:
Exhaust gases
Energy generation
Specific fuel consumption

ABSTRACT

The ceaseless search for renewable sources of energy puts biodiesel as a great alternative to replace oil-based fuels. This work aimed to assess the specific consumption of fuel, thermal efficiency and emission of exhaust gases when crambe biodiesel and diesel oil are used in a diesel-cycle internal combustion engine-generator, with different levels of resistive loads. A diesel-cycle engine generator was used, with 7.36 kW (10 cv) of power and 5.5 kVA/5.0 kW of nominal power, with monophasic output tension of 120/240 V. The used fuels were crambe biodiesel (B100) and diesel oil (B0). Nominal resistive loads applied ranged between 1.0 kW and 5.0 kW. In order to quantify the emission of gases, fuel quality and emission analyzer were used. Crambe biodiesel's data for specific consumption and efficiency of energetic conversion proved to be statistically equal to those of diesel. With the usage of crambe biodiesel there was a significant reduction in the analyzed exhausted gases.

Contents

1. Introduction

The constant concerns about the environment pollution, along with the search for sources which may come to replace those of fossil origin, put the biodiesel as a great alternative to meet the worldwide energetic demands. According to Parente [1], biodiesel is a renewable, biodegradable and environmentally friendly fuel that may replace mineral diesel oil, constituted by a mix of methyl or ethyl esters of fatty acids, obtained from the reaction of transesterification of any triglyceride with a short-chain alcohol, methanol or ethanol. It replaces diesel oil in diesel-cycle engines, with the advantage of not requiring mechanical adaptations [2], also leading to a decrease in the emission of most generated pollutants [3]. Thus, there are several possibilities on how to use biodiesel in urban, road, railroad and waterway transport of passengers and freight, energy generators, stationary engines, etc. [4].

According to Silva et al. [5], the main materials used for the production of biodiesel are vegetable oils (soybean, sunflower,

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http://dx.doi.org/10.1016/j.rser.2014.07.013
1364-0321/

canola, castor bean and palm oil) and animal fat, such as bovine and chicken fat, and also the use of residual oil from frying. In Brazil, most production of biodiesel comes from soybean oil, which provides more than 70% of raw material [6]. That high dependence of the soy culture, along with the fact that it is destined for human nourishment, leads to an increase in the number of researches and incentives to the production of other oilseed cultures with potential to provide biodiesel.

Due to the wide climatic and edaphic diversity, Brazil presents a large capacity to produce different kinds of vegetables, in other words, it means there may be an increase in the parameters for biodiesel production [7]. Among these species, there is one named *Crambe abyssinica* Hochst, which belongs to the *brassicaceae* family and, according to Silva et al. [8], it is an alternative raw-material for the biodiesel production, having a high tolerance to drought conditions and has a short cycle (between 90 and 100 days). It has good adaptability to warm and cold soils and it is resistant for pests and diseases, with an oil content about 35%. It is also a winter culture, with great potential to be constituted into raw material for biodiesel, and acts in crop rotation [4]. The conversion of crambe oil into biodiesel is viable and presents good percentage of fatty acids converted into methyl ester [9].

As it is a winter crop, crambe has attracted the interests of soybean producers at Brazil, as an alternative for the second crop and culture rotation, and also for having low cost and easy production, once its farming is mechanized [10].

With the discovery of crambe's high potential for vegetable oil production, researches have led its use as raw material to biodiesel, a rustic plant that until a short time ago was only used as a forage in culture rotation and soil coverage [11]. Because its oil has a high erucic acid content, 56% Laghetti et al. [12], it gives some interesting properties to the biodiesel obtained from this oil, Wazilewski et al. [13] found that the methyl crambe biodiesel has a higher stability for thermal stress and copper/iron filings contamination when compared to methyl soybean biodiesel. Furthermore it presents an acceptable value for the induction period (P.I) without the need of using synthetic anti-oxidants, 7.6 h according to [14].

Nowadays, it is of highly importance that studies related to performance, specific consumption, efficiency and gas emission generated from combustion, concerning to biodiesel in comparison to mineral diesel oil were done.

In a research on the performance of a diesel-cycle engine generator that used different biofuels from vegetable oils, mixed with mineral diesel oil, Ali et al. [15], showed that the engine's performance was similar to that obtained with diesel oil, which indicated that there would not be any effect in the engine's performance after 200 h of work. Castellanelli et al. [16], when assessing ethyl soybean biodiesel mixes in a direct injection engine, obtained higher performance values for biodiesel B20 if compared to diesel oil, having observed that for mixes B2, B5 and B10, the performance was similar to that of diesel oil.

Cardoso et al. [17] carried out a comparative analysis of the specific fuel consumption and regulated emissions (CO_2, CO, NOx, SO_2 and O_2) of a stationary diesel-cycle engine that operated with diesel and biodiesel (B100), with constant rotation, and observed similar engine performance for both fuels.

Several authors have noticed, in what concerns to the comparison between the usage of biodiesel and diesel oil, biodiesel's potential in reducing emissions of particulate material and smoke, just like Pereira et al. [18], who obtained reductions in the emissions of carbon monoxide (CO) and Sulfur Dioxide (SO_2).

In that sense, the objective of this study was to assess the specific fuel consumption, efficiency and emission of exhaust gases of an engine-generator set, by using crambe biodiesel compared to mineral diesel oil.

2. Material and methods

The crambe biodiesel was obtained by transesterification reaction with potassium hydroxide (KOH) as catalyzer, 1% of the oil weight, and methanol as alcohol (25% of oil volume). First, methanol and potassium were mixed vigorously for 10–20 min. Then the potassium methoxide formed was mixed with the crambe oil in a round bottom flask and stirred continuously using a magnetic stirrer and maintained at a temperature of 60 °C. Once the reaction time was over, the contents were transferred into a separating funnel and allowed for 24 h to separate into two layers. After separating, the biodiesel was submitted to washing process with distilled warm water. And for last it was submitted to an incubator to remove excess water content.

The kinematic viscosity was obtained through a Cannon-Fenske N° 150 capillary viscometer in thermostatic bath at 40 °C. Flash point was obtained with the heating of aliquots of the fuels controlling its temperature, and for each rising Celsius degree a fire was pointed and when fuel entered in combustion the temperature was written down. And specific gravity was obtained at 20 °C with a pycnometer and a four decimal precision balance.

For the tests, a diesel-cycle engine-generator model BD 6500CF with 7.36 kW (10 cv) of power and 5.5 kVA/5.0 kW of nominal power with monophasic output tension of 120/240 V was used.

In order to measure the mass of fuel consumed, an external storage tank was used, which was weighted on a precision scale, thus providing the data for fuel consumption during tests with the engine-generator set The duration of each test was accounted by a digital stopwatch, what allowed the obtainment of data for fuel consumption. Eq. (1) shows the fuel consumption calculus carried out in each performance test of the set

$$\mathrm{Cons} = \frac{\mathrm{IM} - \mathrm{FM}}{\Delta t} \tag{1}$$

where Cons = Fuel consumption, kg s^{-1}; IM = Initial mass of the fuel, kg; FM = Final mass of the fuel, kg; Δt = Test duration, s.

The charge simulation in the generator was performed by means of a bank of electric resistances, whose powers are controlled by keys in an electric panel. The nominal loads adopted were: 1.0 kW; 2.0 kW; 3.0 kW; 4.0 kW; 5.0 kW. The adopted charges were the same, in order to allow comparison between mineral diesel oil and biodiesel.

The performance assessment of the set was done based on the specific consumption (SFC) and energetic conversion efficiency (η), of the engine-generator set The SFC was determined according to the resistive load variation of the engine-generator, running on with mineral diesel oil (B0) and crambe biodiesel (B100)

$$\mathrm{SFC} = \frac{3600 * \mathrm{Cons}}{V * I} \tag{2}$$

where SFC = Specific fuel consumption, g kW^{-1} h^{-1}; Cons = Fuel consumption, kg s^{-1}; V = Output voltage, V; I = Electric current, A.

In order to determine the calorific value of the fuel mixes, a calorimeter model E2K was used. For this test, portions of approximately 0.5 g of fuel were separated. The method to determine superior calorific value with a calorimeter comprises pressurizing with a pump the adiabatic container that keeps the sample, such container is coupled to the ignition chord. The pressure kept in calorimeter E2K was 30 atm (3.00 MPa). The tests with incomplete combustion were ignored. In that sense, it was possible to determine the higher heating value of the fuels.

The lower heating value (Eq. 3) of the compositions was determined by the equation described in Volpato et al. [2] and takes into account the higher heating value

$$\mathrm{LHV} = \mathrm{HHV} - 3.052 \tag{3}$$

where LHV = Lower heating value, MJ kg^{-1} and HHV = Higher heating value, MJ kg^{-1}.

Another parameter used in the assessment of the engine-generator set was the efficiency of conversion of the fuel's chemical energy into electricity by the engine-generator. The calculus of the efficiency of the engine-generator was performed with

$$\eta = \left(\frac{3600}{\text{LHV} \times \text{SFC}}\right) \times 100 \tag{4}$$

where η=Set efficiency, %; SFC=Specific fuel consumption, g kW^{-1} h^{-1}; LHV=Lower heating value, MJ kg^{-1}.

To quantify the emission of gases, an analyzer of quality of combustion and emissions was used (Model PCA3-285KIT/24-8453, by Bacharach). The analyzer has calibration certificate N° 1011/AN5420, dated 24/11/2010 for temperature and concentration items. For the emission tests, the equipment's capture probe was exposed in the gas exhaust area until the values were stabilized. This process was repeated for four consecutive times. The quantified gases were the emissions of carbon monoxide (CO), Nitric Oxide (NO), Nitrogen Oxides (NOx) and Sulfur Dioxide (SO_2). The averages of the treatments were compared by Tukey's test at 5% significance.

3. Results and discussion

Table 1 shows the properties obtained at laboratory for the crambe biodiesel and mineral diesel used for the tests with the engine-generator. The mean of higher heating value presented to be 9.3% lower for the crambe biodiesel. The kinematic value was very high for the crambe biodiesel (6.00 mm^2 s^{-1}). These two properties are very important for helping understand the behavior of the engine-generator when using these fuels.

3.1. Performance results

Fig. 1 shows the behavior of the engine's SFC according to the variation of resistive load applied to the generator. Even though there was no statistical differences, crambe biodiesel showed higher average SFC, approximately 1.2% superior to diesel.

Table 1
Means of analyzed properties for crambe biodiesel and diesel.

Properties	Crambe biodiesel	Diesel
Higher heating value (MJ kg^{-1})	39.569	43.616
Kinematic viscosity, 20 °C (mm^2 s^{-1})	6.00	3.01
Specific gravity (g cm^{-3})	0.872	0.845
Flash point (°C)	136	52.5

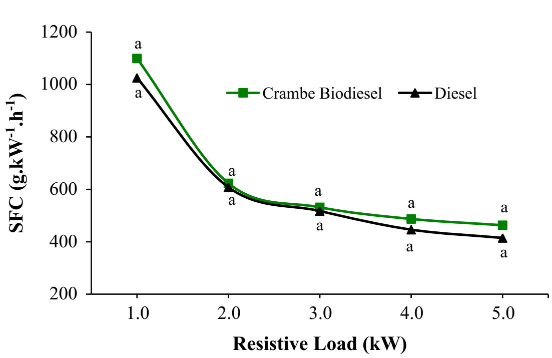

Fig. 1. Specific fuel consumption in relation to the applied resistive load. Treatment averages followed by different letters differ significantly from each other by Tukey's test at 5% significance.

According to Torres et al. [19] in tests with stationary single cylinder Agrale engines, model M-85 with 7.36 kW of power, there were no significant differences concerning to the usage of diesel oil and biodiesel (B100), with close results. The specific fuel consumption with B(100) was approximately 20% higher than that of diesel oil. Lopes et al. [20], when working with biodiesel that came from residual frying oil, observed a consumption increase of 18%.

The efficiency in converting the fuel's chemical energy into electric energy in the engine-generator set was calculated as shown in Fig. 2. No statistical differences were found for the efficiency of the engine-generator set used in the chemical conversion of fuel into electric energy, given that crambe biodiesel obtained average efficiency of 0.76% more than that of diesel. These results confirm what was observed by Barbosa et al. [21], who verified that by using biodiesel (B100), the engine's efficiency was averagely 4% higher when compared to mineral diesel oil. In another study, Silva et al. [5] verified that for all studied nominal charges, diesel's efficiency did not overcome 3% of that of biodiesel.

3.2. Emissions results

Regarding greenhouse gas emissions by the engine-generator, the average emissions were evaluated and compared for each resistive load between mineral diesel (B0) and crambe biodiesel (B100), for the following gases: carbon monoxide (CO) Nitric Oxide (NO), Nitrogen Oxides (NOx) and Sulfur Dioxide (SO_2).

Regarding to carbon monoxide (CO) it was observed that the crambe biodiesel presented low emissions for all loads, except for 2 kW, where diesel had similar emissions to biodiesel (Fig. 4). As for the emissions of carbon monoxide, it was possible to observe that crambe biodiesel showed 43.42% less emission than diesel (B0) (Fig. 3). Peterson and Reece [22] verified, with the usage of biodiesel, a reduction of 7.6% of CO. In a study that used biodiesel, Makareviciene and Janulis [23] observed an even more significant

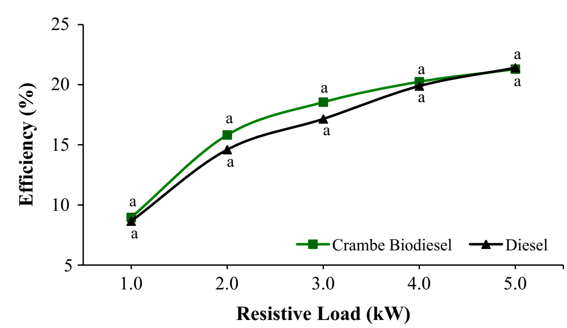

Fig. 2. Efficiency of the engine-generator set in converting the fuel's chemical energy into electric energy. Treatment averages followed by different letters differ significantly from each other by Tukey's test at 5% significance.

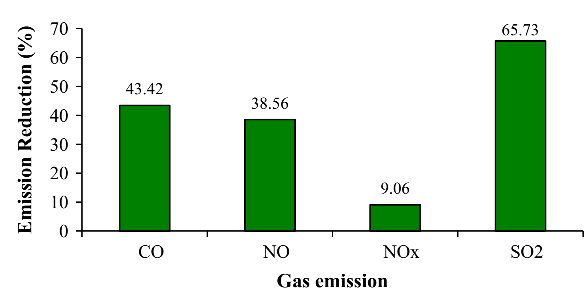

Fig. 3. Percentage average reduction of emissions from studied gases when replacing diesel by crambe biodiesel.

reduction of CO, an average of 50%, very close to the value found in this study.

For nitric oxide (NO) emissions, the crambe biodiesel showed significant reductions for all loads, and from 3 kW to higher loads the difference between the fuels increased (Fig. 5). Thus the overall average reduction was 38.56% (Fig. 3). This result corroborates with the findings by Pereira et al. [18], using soybean oil biodiesel found emissions of NO similar or lower than the pure diesel.

For Nitrogen Oxides (NOx) the two fuels showed very close emission values for all resistive loads, having crambe biodiesel a mean of 9.06% lower, seeking that for 2 kW (Fig. 6) crambe biodiesel showed much lower NOx emission and were statistically different from diesel. This result corroborates those found by Maziero et al. [24], in which a research using sunflower biodiesel, they observed a reduction of 5.7% and Vedaraman et al. [25] using methyl ester of Sal oil, showed an average reduction of 12% when

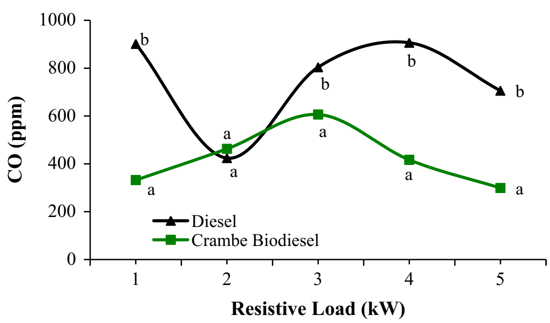

Fig. 4. Carbon monoxide emissions for both fuels at different resistance loads. Treatment averages followed by different letters differ significantly from each other by Tukey's test at 5% significance.

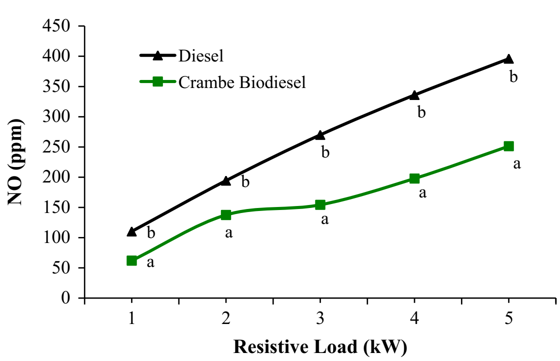

Fig. 5. Nitric oxide emissions for both fuels at different resistance loads. Treatment averages followed by different letters differ significantly from each other by Tukey's test at 5% significance.

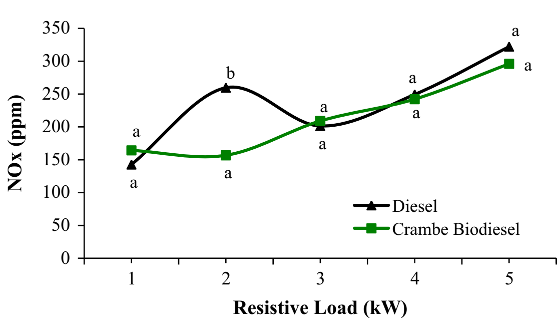

Fig. 6. Nitrogen oxides emissions, for both fuels, at different resistance loads. Treatment averages followed by different letters differ significantly from each other by Tukey's test at 5% significance.

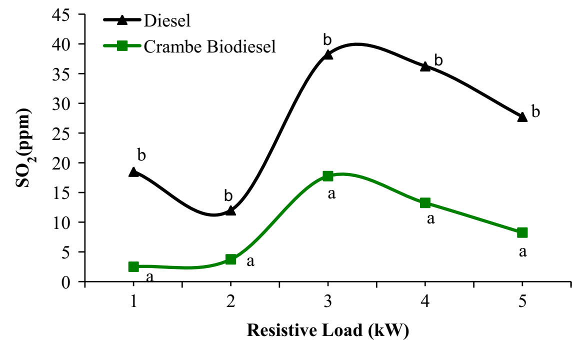

Fig. 7. Sulfur dioxide emission for both fuels at different resistance loads. Treatment averages followed by different letters differ significantly from each other by Tukey's test at 5% significance.

compared to diesel. Although Schumacher et al. [26] obtained an increase of NOx emissions about 11.6% when using pure biodiesel.

Sulfur Dioxide (SO_2) emissions from crambe biodiesel showed lower values and statistically difference to diesel, for all loads (Fig. 7), this could be explained by the low amount of sulfur present in biodiesel. Vedaraman et al. [25] cites that fuels based on vegetable oils contain a low amount of sulfur, nitrogen and aromatics in their composition. The mean value for SO_2 emission reduction, of all resistive loads, was about 65.73% when compared to diesel. Pereira et al. [18] observed in their study that besides the reduction of SO_2, there were no noticeable differences in the generation of energy using biodiesel.

With this, it seems that the crambe biodiesel is a great alternative to replace diesel as well as ensuring power generation similar to this mineral oil, thus a reduction of gas emissions, which is of high importance to the environment.

4. Conclusion

No statistical differences were observed for the average fuel consumption, between diesel and crambe biodiesel, as well as for the energetic conversion efficiency of the generator.

For all analyzed emissions, crambe biodiesel presented statistical differences in relation to diesel, and obtained a reduction of 43.42%, 38.56%, 9.06%, 65.73% for gases (CO), (NO), (NOx) and (SO_2) respectively.

Acknowledgments

The authors thank CNPq (National Counsel of Technological and Scientific Development).

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